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(71) Applicant (for all designated States except US): **DOW GLOBAL TECHNOLOGIES, INC.** [US/US]; Washington St., 1790 Bldg., Midland, MI 48674 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **MAURER, Myron, J.** [US/US]; 3125 Hidden Timber Drive, Lake Orion, MI 48359 (US). **ROGERS, Steve, J.** [US/US]; 8618 Far Ravine Drive, Pinckney, MI 48169 (US). **TUSIM, Martin,**

H. [US/US]; 1408 Peppermill Circle, Midland, MI 48642 (US).

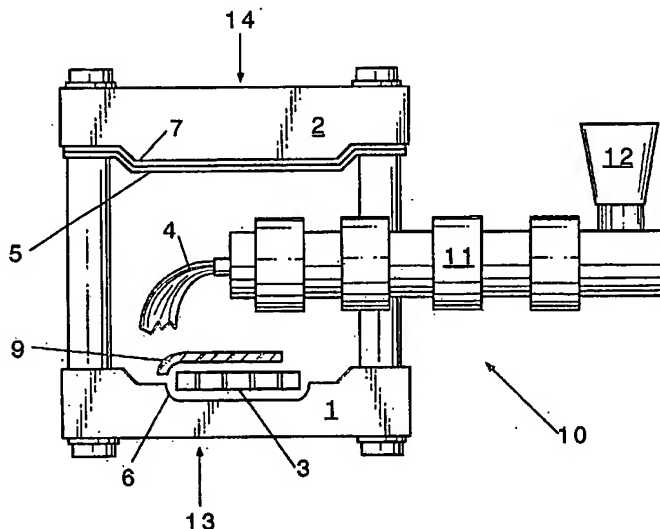
(74) Agent: **COHN, Gary, C.**; Gary C. Cohn PLLC, 4010 Lake Washington Blvd. NE, Suite 105, Kirkland, WA 98033 (US).

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(54) Title: METHOD OF PREPARING VEHICLE DOOR PANELS



(57) Abstract: Composite structural parts such as energy-absorbing automotive parts are made by inserting a thermoplastic energy-absorbing component into a mold, injecting a substrate polymer into the mold, and molding the energy-absorbing component and the substrate polymer to form a composite in which the substrate polymer is affixed to the energy-absorbing component without use of an intervening adhesive, and the structure of the energy-absorbing component is substantially preserved. The parts are made without secondary foam tooling, and thus can be produced at lower cost. In preferred embodiments, the substrate polymer and the energy-absorbing component are made from the same polymeric material, or different polymeric materials that are classified the same for recycling purposes. This allows scrap, used and damaged parts to be recycled without the need to separate them into their component parts.

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## METHOD OF PREPARING VEHICLE DOOR PANELS

This invention relates to methods of making composite panels containing an energy absorbing component.

5 In order to meet government-mandated crashworthiness standards, many automotive parts include a passive energy absorbing countermeasure. Examples of such standards in the United States include Federal Motor Vehicle Safety (FMVSS) 201U—Occupant Head Impact Protection, FMVSS 208—Occupant Knee Impact Protection and FMVSS 214—Occupant Side Impact Protection. The  
10 energy absorbing countermeasure absorbs energy upon impact during a collision, thereby reducing injury to vehicle occupants and often reducing damage to the vehicle or other property. Examples of such automotive parts are pillars, door trim panels, knee bolsters and fascia, among others. These parts include, in addition to the energy-absorbing countermeasure layer, a relatively rigid substrate material  
15 that provides overall shape and structural support. Sometimes, the part will also include a show surface such as a polymeric skin. In addition to providing personal injury protection, these parts are designed to meet various other functional and aesthetic needs. Thus the parts are often complex in design and construction.

In order to reduce costs and vehicle weight, these parts are increasingly  
20 made from a structural plastic material such as a thermoplastic olefin (TPO) or polypropylene (PP), although in some cases other polymers and thermoset materials can be used. The energy-absorbing countermeasure is typically a polyurethane foam, expanded polypropylene bead foam, or a structural thermoplastic component such as a ribbed cartridge. A common process for  
25 making the parts is to mold the substrate material into the required shape. The energy absorbing countermeasure is produced and shaped separately, usually in multiple foam expansion and secondary tooling steps (as in a steam chest mold), and is affixed to the substrate material using a hot melt or other form of an adhesive. Show surfaces, if any, are in most instances separately formed and  
30 applied, although it is known to form the substrate in a mold containing a skin material, so that the substrate is formed and laminated to the skin layer in one operation. Thus, the creation of these parts tends to be a cumbersome process involving several manipulative steps. This increases the overall cost of the part significantly.

Alternative processes are described in, for example, US 6,171,419 to Heiman et al. and US 5,571,355, 5,397,409 and 5,387,390 to Kornyo. In these methods, a vinyl sheet is positioned onto the surface of a vacuum mold and a foamable composition is injected into the mold. The foamable composition cures in the mold to form a structural foam that is adhered to the vinyl sheet. The vinyl sheet may be a thin foam laminate. In US 5,387,390, a soft foam having a specified density may be affixed to the plastic sheet using an adhesive prior to injecting the foamable composition, in order to provide localized cushioning for an interior arm rest for a vehicle door.

As it is desirable to reduce production costs for these parts, a process whereby they can be produced simply at low cost is desired.

This invention is a method of making a shaped part having an integrated energy-absorbing component, comprising (a) positioning a previously-formed thermoplastic energy-absorbing component into a mold; (b) introducing a molten thermoplastic substrate polymer into the mold, and (c) molding the substrate polymer in the mold under conditions sufficient to form said thermoplastic polymer into a shaped substrate and to adhere the thermoplastic energy-absorbing component to said substrate while substantially retaining the structure of the thermoplastic energy-absorbing component.

This process provides a simplified and inexpensive method of making shaped parts that include an energy-absorbing component. In this method, the substrate is molded and affixed to the energy-absorbing component in a single operation. This eliminates the need to adhere separately formed components together.

Furthermore, this invention in certain aspects allows for substantial reduction or even elimination of secondary tooling of the energy-absorbing component. Particularly when it is a foam, the thermoplastic energy-absorbing component can be shaped within the mold at the same time the substrate polymer is molded. For that reason, it is not necessary to tool the energy-absorbing component into its final shape prior to forming the part. All that is necessary is that the energy-absorbing component be cut into appropriate dimensions for insertion into the mold. This greatly simplifies the preparation of the energy-absorbing component of the part.

Figures 1 and 1A are cross-sectional schematics of an embodiment of the

method of the invention.

Figure 2 is a cross-sectional view of an embodiment of a composite part made in accordance with the invention.

Figure 3 is an isometric view of an embodiment of an energy-absorbing component for use in the invention.

In this invention, shaped composite parts having an integral energy-absorbing component are prepared. The composite part contains at least two components: (1) a shaped thermoplastic substrate and (2) a thermoplastic energy-absorbing component. The substrate is adhered to the thermoplastic energy-absorbing component without an intervening adhesive.

In the method, the composite part is formed in a suitable mold assembly. The mold assembly typically will consist of two mold halves. One half (typically the so-called "male" or "core" half) will have a mold surface shaped to form one surface of the composite part. The other half (typically the "female" half) will similarly have a shaped mold surface that is shaped to form the other surface (typically a "show" surface) of the composite part. The mold will also be adapted to hold a previously-formed thermoplastic energy-absorbing component, as described more below, into a desired position so that the energy-absorbing component is positioned and oriented in a desirable way in the finished composite part.

One embodiment of a suitable mold assembly is shown in Figures 1 and 1A. In Figure 1, mold assembly 10 is shown in an open position. Mold half 1 has a shaped mold surface 6 that defines the shape of one surface of the composite part to be molded. A previously-formed thermoplastic energy-absorbing component 3 (as shown, a polymer foam) is positioned within mold half 1. Molten thermoplastic substrate polymer 4 is injected into the mold over energy-absorbing component 3 and into mold half 1. The mold assembly also includes mold half 2 having a shaped mold surface 7. Shaped mold surface 7 defines the exterior shape of the composite part that is to be formed.

Mold halves 1 and 2 move in the relative (to each other) directions indicated by arrows 13 and 14, respectively, to bring the filled mold assembly 10 into a closed position. Of course, one of the mold halves may be kept in a fixed position. As shown in Figure 1A, substrate polymer 4 has been shaped by the mold into a desired configuration to form shaped substrate 20. Substrate 20 becomes adhered to energy-absorbing component 3, thereby forming a composite part. No separate

adhesive is required to adhere substrate 20 to energy-absorbing component 3. During the molding process, substrate polymer 4 wets out the surface of energy-absorbing component 3 so that good adhesion is formed when the substrate polymer 4 hardens into substrate 20.

5       The embodiment shown in Figures 1 and 1A includes various optional features. In Figure 1, it is seen that energy-absorbing component 3 does not conform to the shape of surface 6 of mold half 1. In such an embodiment, the energy-absorbing component itself may be shaped somewhat during the molding process, particularly in cases where the energy-absorbing component is a foam.  
10       This is illustrated in Figure 1A, where the surface of energy-absorbing component 3 is shaped during the molding process to conform to the shape of interior surface 6 of mold half 1. It is often helpful to pre-heat the energy-absorbing component 3 prior to forming the composite part. This allows the energy-absorbing component to become more pliable and therefore more easily shaped in the mold. Preheating  
15       is of course performed such that the ability of the energy-absorbing component to absorb energy is not destroyed.

      In-mold shaping of the energy-absorbing component represents a preferred manner of forming composite parts in which the energy-absorbing component must assume a complex shape. The in-mold shaping eliminates complex secondary  
20       tooling of the energy-absorbing component prior to forming the part. It is only necessary to cut the energy-absorbing component into the approximate dimensions that will be needed in the composite part. Final, complex shaping is then achieved in the molding process. This allows regularly-shaped pieces of the energy-absorbing component (i.e., those having simple and preferably uniform cross-  
25       sections) to be used as starting materials in the molding process.

      If the energy-absorbing component forms an exterior surface of the shaped part, it is possible that it will not be shaped sufficiently during the molding process to conform to the surface of the mold. Resulting voids can be filled with the structural polymer during the molding process.

30       Another optional feature shown in Figures 1 and 1A is the use of previously-formed skin 5. Skins may be provided for many purposes, but are most often used for aesthetic reasons. As shown in Figures 1 and 1A, skin 5 is placed into mold half 2 in contact with interior surface 7, and drawn into the mold such that it assumes approximately the three-dimensional features of interior mold

surface 7. In this embodiment, skin 5 is separated from energy-absorbing component 3 by structural member 20 in the finished part. However, if desired, a skin can be placed on either or both sides of the composite part. For example, a skin can be placed in mold half 1 in contact with interior surface 6, to form a skin on the other side of the part, in contact with a surface of energy-absorbing component 3. This can be instead of or in addition to skin 5 as shown in Figures 1 and 1A.

As before, no separate adhesive is used to adhere skin 5 to structural member 20, as molten substrate polymer 4 wets out the surface of skin 5 before hardening, thereby forming a strong adhesive bond.

Molding conditions are selected to accomplish several things. The substrate polymers must of course fill the empty portion of the mold cavity and be shaped into the desired configuration. In addition, it is important to select molding conditions such that the ability of the energy-absorbing component to absorb energy is substantially preserved. By "substantially preserved", it is meant that the energy-absorbing component retains at least 50%, more preferably at least about 75%, more preferably at least about 85% of its original ability to absorb energy upon impact in at least one direction. In the case where the energy-absorbing component is a foam, it retains at least 50%, more preferably at least about 75%, more preferably at least about 85% of its original volume in the composite part as it is demolded. Cell collapse and/or compression may occur at the interface of the energy-absorbing component and the structural member (shown at 23 in Figures 1A and 2), at places where the energy-absorbing component contacts the surface of the mold cavity, and in areas where the energy-absorbing component is shaped during the molding process (such as areas 21 and 22 in Figures 1A and 2).

Thus, for example, the mold assembly may or may not be heated. If the mold assembly is heated, either the mold temperature is kept below that temperature at which the energy-absorbing component will significantly distort or collapse (in the case of a foam), or else mold residence times are kept short enough that such distortion and/or collapse does not occur before the composite part is demolded and cooled. In all instances, before demolding the composite part, the mold is brought to a temperature below the hardening temperature of the structural polymer, so that the polymer hardens within the mold and can be

demolded without significant distortion.

Clamp pressures are similarly chosen with the foregoing needs in mind. Clamp pressures are sufficient to shape the thermoplastic polymer into the desired shape while substantially preserving the ability of the energy-absorbing component to absorb energy.

When a skin is applied, the mold is conveniently equipped with a vacuum assist to draw the skin against the corresponding internal surface of the mold. The skin is preferably heated to an elevated temperature below its melting temperature to soften it and therefore enable it to more easily conform to the surface of the mold.

The process of the invention is readily adapted to being used in conjunction with various conventional molding processes, with minimal modification being needed other than to design the mold cavity to accommodate the energy-absorbing component. Various extrusion, injection molding, injection compression, vacuum thermoforming, and compression molding techniques can be used, together with the corresponding equipment. Low pressure melt compression molding techniques are particularly suitable. In some of these methods, the mold may be oriented vertically, such as in some injection compression molding processes.

The energy-absorbing component (1) is a thermoplastic; (2) is previously-formed (i.e., fabricated in a separate step prior to introduction into the mold to make the shaped part, and (3) contains gas-filled voids which provide at least a portion of its ability to absorb energy. In order to provide energy-absorption properties, the energy-absorbing component advantageously has a compressive strength, in at least one direction, of no greater than about 150 psi (pounds per square inch) (1034 kPa) at 25% strain, more preferably no greater than about 125 psi (861 kPa) at 25% strain, even more preferably no greater than 100 psi (689 kPa) at 25% strain, and most preferably no greater than about 50 psi (345 kPa) at 25% strain, and at least about 10 psi (69 kPa) at 25% strain, as measured in accordance with ASTM D3575-93 (Suffix D). The energy-absorbing component may be more or less isotropic, in that the compressive strength may be substantially the same in all directions (isotropic), or may have a significantly higher compressive strength in one direction than in other directions (anisotropic). Anisotropic energy-absorbing components may have a compressive strength in one direction that is from 1.25, preferably from about 1.5, more preferably from about



2 to about 10 times the compressive strength in one or more other directions. When an anisotropic energy-absorbing component is used, it is preferably oriented in the composite part in such a manner that the direction of maximum compressive strength is approximately aligned with the direction along which a cushioning effect is desired (i.e., that in which an impact is expected). In particular, the direction of maximum strength of the energy absorbing component and the direction in which impact is expected should differ by less than 45°, preferably less than 30° and especially less than 15°.

Two suitable types of energy-absorbing components are polymer foams and modular energy-absorbing assemblies as described below.

Foam used as the energy-absorbing component is preferably substantially closed-celled, having a closed cell content of at least about 50%, more preferably of at least about 70%, even more preferably at least about 80% and most preferably at least about 85%.

Suitable foam energy-absorbing components desirably have a density of less than 20 pounds per cubic foot (320 kg/m<sup>3</sup>), preferably from about 0.5 per cubic foot (pcf) (8 kg/m<sup>3</sup>), more preferably from 1.0 pcf (16 kg/m<sup>3</sup>), especially from 1.25 pcf (20 kg/m<sup>3</sup>), most preferably from 1.5 pcf (24 kg/m<sup>3</sup>), preferably to 12 pcf (192 kg/m<sup>3</sup>), more preferably to 10 pounds per cubic foot (160 kg/m<sup>3</sup>), and most preferably to 8 pounds per cubic foot (128 kg/m<sup>3</sup>), prior to the insertion into the mold for forming the composite part.

The manner of foam production is not particularly critical, although in some cases the foam manufacturing technique may impart properties to the foam that are desirable for particular applications. Thus, foam energy-absorbing components may be made in an extrusion process such as is described, for example, in U. S. Patent Nos. 4,694,027 5,348,795; 5,527,573 and 5,567,742 to Park (all incorporated herein by reference), by a coalesced strand process as described in US 6,213,540 to Tusim et al. (also incorporated by reference), or via a bead-foam process, an example of which is described in US Patent No. 4,866,098 to Tusim (incorporated herein by reference). In general, extruded foam (including coalesced strand foam types) and expanded polypropylene bead foam are preferred foam types of energy-absorbing component. After extrusion or expansion, the foam may be cut to a size and shape that approximates its final shape in the composite part and fits into the mold.

Among anisotropic foams, of particular interest are coalesced strand foams of the type described in US Patent No. 6,213,540 to Tusim et al and US Patent No. 4,824,720, both incorporated herein by reference. These coalesced strand foams tend to be highly anisotropic, with the highest compressive strengths generally being observed in the extrusion direction. As described in US 6,213,540, those thermoplastic foams may be prepared by the extrusion foaming of a molten thermoplastic composition utilizing a die including a multiplicity of orifices. The orifices are arranged such that contact between adjacent streams of the molten extrudate occurs during the foaming process and the contacting surfaces adhere to one another well enough to result in a unitary structure that does not strain delaminate under stresses encountered in preparing, shaping, and forming the foam product. The coalesced strand foam may be a coextrudate comprising strands of two or more different densities:

The coalesced strand foam may include missing strands or designed voids, i.e., exhibit a profile or cross section transverse to the extrusion direction which is discontinuous. Methods of forming stranded foam articles having designed voids are described in U.S. Pat. No. 4,801,484, which is incorporated by reference herein.

Alternative methods of forming foam articles exhibiting anisotropic strength are described in US Patent 6,213,540 to Tusim et al, incorporated herein by reference.

Bead foams included foams prepared by heating blowing agent-impregnated thermoplastic beads such that they expand and adhere to form a foam structure. The thermoplastic may be polystyrene, a polystyrene copolymer, such as a styrene/polyphenylene oxide copolymer (commercially available as Noryl™, from GE Plastics. A commercial grade of a styrene/polyphenylene oxide bead foam copolymer is available as GECET™ from Huntsman Chemicals. The thermoplastic may also be a polyolefin, such as a lightly crosslinked polyethylene.

Yet another suitable foam energy-absorbing component is a composite foam structure comprising a first segment of an extruded, preferably anisotropic thermoplastic foam (such as described above) and a second segment shaped foam of a part comprising an isotropic foam wherein the first foam segment and second, isotropic foam part intersect along at least one common surface. Preferably, the first foam segment is an anisotropic foam that comprises a plurality of extruded strands of foam which are fused together wherein all of the strands of the foam are

oriented in the same direction. The second foam segment is preferably a bead foam. Such composite foam structures are described, for example, in WO 04/003064, which is incorporated herein by reference.

Alternative energy-absorbing components include a modular energy  
5 absorbing assembly comprising a base having a plurality of separated recesses,  
and an overlay which covers the openings to the recesses. The recesses each have  
a floor and walls extending from the base to the floor to form, together with the  
overlay, a plurality of gas-filled enclosed spaces. The walls are deformable such  
that the recesses are at least partially compressed during energy absorption.  
10 Suitable base components of such a modular energy absorbing assembly are  
described in U. S. Patent No. 6,247,745 to Carroll III et al., incorporated herein by  
reference. The overlay is typically a thermoplastic sheet or film that is adhered to  
the base through a twin sheet thermoforming, blow molding or melt adhesion  
process.

15 An embodiment of such a modular energy-absorbing assembly is shown in  
Figure 3. In Figure 3, modular energy-absorbing assembly 30 includes base 31  
having a plurality of recesses 32. Recesses 32 each include a floor 34 and walls 33.  
Recesses 32 are each open to the (as shown) bottom of base 31. Overlay 35 is  
adhered to the bottom of base 31, covering the openings of each of recesses 32 to  
20 form a gas-filled enclosed space defined by each recess 32. As shown, the walls of  
adjacent recesses 32 can be connected by support members 36 to provide increased  
stability and rigidity. Preferably, modular energy-absorbing assembly 30 is  
oriented in the shaped part such that floors 34 are substantially perpendicular to  
the expected direction of impact, and the walls 33 are inclined at an angle of from  
25 about 0 to about 45 degrees from such expected direction of impact.

Alternatively, or in addition to the overlay covering the openings to the  
recesses, a second overlay similar to overlay 35 may be positioned at the top (in the  
orientation shown in Fig. 3) of the modular energy-absorbing assembly, such  
second overlay being affixed (directly or indirectly) to the floors of the recesses.  
30 When such a second overlay is used, energy-absorbing, gas-filled enclosed spaces  
are defined by base 31, the second overlay, and the exterior walls 33 of recesses 32.

Multiple energy-absorbing assemblies of this type can be stacked and/or  
juxtaposed with an overlay, as described in published United States Patent  
Application 2002/0017805A1, particularly in figures 13-15 thereof, incorporated

herein by reference.

Both the energy-absorbing component and the substrate are made from a thermoplastic polymer. Suitable thermoplastics include polyolefins such as low density polyethylene (LLDE), high density polyethylene (HDPE), so-called  
5 "substantially linear" polyethylene, polypropylene, and co-polymers of ethylene or propylene and one or more copolymerizable monoethylenically unsaturated monomers. Examples of preferred polyethylenes include low density polyethylene homopolymers and substantially linear ethylenic polymers having a melt flow ratio,  $I_{10}/I_2$ , greater than or equal to about 5.63, a molecular weight distribution,  
10  $M_w/M_n$ , defined by the equation  $M_w/M_n \leq (I_{10}/I_2) - 4.63$ , and a critical shear rate at onset of surface melt fracture of at least 50% greater than the critical shear rate at the onset of surface melt fracture of a linear olefin polymer having about the same  $I_2$  and  $M_w/M_n$ . Substantially linear ethylenic polymers as set forth above are described in U.S. Patent Nos. 5,340,840 and 5,272,236, which are hereby  
15 incorporated by reference. Preferred polyolefins other than the polyethylenes include polypropylene homopolymers and copolymers of polypropylene that are comprised of at least about 50% polymerized propylene by weight. Other suitable polyolefins include branched polypropylene homopolymers and branched copolymers of polypropylene. Examples of such copolymers include copolymers of  
20 ethylene and acrylic acid, methylacrylic acid or  $C_{1-4}$  alkyl esters; ethylene vinylacetate copolymers; ethylene/carbon monoxide copolymers; copolymers of ethylene and an alpha-olefin having ultra low molecular weight (i.e., densities less than 0.92 g/cc); and blends of two or more of the above resins.

Suitable polypropylene polymers are described in U. S. Patent Nos.  
25 4,916,198 and 5,554,668. Commercially available polypropylenes that are useful include INSPIRE™ C702-20 and C703-35U polypropylene resins, available from The Dow Chemical Company.

Yet other suitable polyolefins (for both the energy-absorbing component and the substrate) are thermoplastic polyolefin (TPO) polymers. Examples of suitable  
30 TPOs include those described in US Patent No. 5,861,463 to Sehanobish et al., incorporated herein by reference. TPOs are blends of polypropylene polymer, a modifier, and optionally fillers and other compounding ingredients. TPOs are multiphase polymer blends where the polypropylene polymer forms a continuous matrix phase and the modifier and fillers are the dispersed components. The

polypropylene matrix imparts tensile strength and chemical resistance to the TPO while the modifier imparts flexibility and impact resistance. The TPO may contain a compatibilizer to compatibilize the polypropylene polymer and modifier phases, such as an ethylene-propylene copolymer as described in US Patent No. 6,245,856 to Kaufman et al. The polypropylene polymer phase of the TPO preferably has a relatively high melt flow rate (MFR), such as from about 20 to 100, with a MFR of 35 to 70 being preferred. The polypropylene polymer component will typically comprise 50 to 88 weight percent of the TPO with a polypropylene content of 65 to 75 weight percent being preferred.

The modifier will typically have a melting point lower than that of the polypropylene polymer, and preferably has a melting point below about 125°C. The modifier is suitably an ethylene-propylene copolymer, ethylene-propylene-diene terpolymer, other ethylene-alpha olefin copolymers such as ethylene-butene and ethylene-octene copolymers. Other suitable ethylene type resin modifiers include medium density polyethylene (MDPE), high density polyethylene (HDPE) (for example, those made using Ziegler catalysts as in U.S. Pat. No. 4,076,698), ethylene/ester copolymers, ethylene/vinyl acetate copolymers, copolymers of ethylene and ethylenically unsaturated carboxylic acids, homopolymers and copolymers of  $\alpha$ -ethylenics, etc. The polyethylene type resin modifiers are comprised primarily of ethylene monomeric units, and more preferably are comprised of at least 80% ethylene monomeric units by weight. Examples of preferred polyethylene type resin modifiers include low density polyethylene homopolymers and substantially linear ethylenic polymers having a melt flow ratio,  $I_1/I_2$ , greater than or equal to about 5.63, a molecular weight distribution,  $M_w/M_n$ , defined by the equation  $M_w/M_n \leq (I_1/I_2) - 4.63$ , and a critical shear rate at onset of surface melt fracture of at least 50% greater than the critical shear rate at the onset of surface melt fracture of a linear olefin polymer having about the same  $I_2$  and  $M_w/M_n$ . Other preferred polyethylene type resin modifiers are homogeneously branched substantially linear ethylene/ $\alpha$ -olefin interpolymers having a density from about 0.89 g/cc to about 0.92 g/cc, a molecular weight distribution ( $M_w/M_n$ ) from about 1.8 to about 2.8, a melt index ( $I_2$ ) from about 0.001 grams/10 minutes to about 10 grams/10 minutes, no high density fraction, a single melting peak as measured using differential scanning calorimetry, a critical shear stress at onset of gross melt fracture greater than  $4 \times 10^6$  dynes/cm<sup>2</sup>, and a slope of

strain hardening coefficient from 1.3 to 2.3. These homogeneously branched substantially linear ethylene/ $\alpha$ -olefin interpolymers are described in U.S. Pat. No. 5,677,383 which is incorporated by reference herein. Examples of commercially available polyethylene type resins which are useful as an elastomeric component  
5 in TPOs are substantially linear ethylenic polymers sold by Dow Chemical Company under the mark "Affinity" and low density polyethylene sold by Dow under the mark "Elite".

The thermoplastic used as the substrate polymer or in the energy-absorbing component may also be an alkenyl aromatic polymer, such as polystyrene or  
10 copolymer of styrene and a copolymerizable monomer. Other suitable thermoplastics include polyesters, polyamides, polyvinylchloride, polyvinylidene chloride and polycarbonates.

It is particularly preferred that the energy-absorbing component and the substrate be of the same material, or else be made of polymers that are classified  
15 as the same for recycling purposes. This allows scrap from both the substrate and the energy-absorbing components to be recycled together, thus eliminating the need to disassemble the shaped part and segregate the different materials. Similarly, defective parts can be recycled easily without separating them into their constituent components. The shaped panel is recycled easily at the end of its  
20 useful life, as it is unnecessary to delaminate the various components in order to segregate them for separate recycling. Most preferably, the energy-absorbing component and the substrate polymer are each the same and are each polypropylene or TPO.

The substrate, the energy-absorbing component, or both may contain  
25 various additives such as fillers, reinforcing agents, colorants, antioxidants, preservatives, flame retardants, slip agents, lubricants, mold release agents, and the like.

The substrate is typically relatively stiff (due to polymer selection, density, thickness and/or design) compared with the energy-absorbing component and thus  
30 provides rigidity to the composite part.

The substrate polymer may contain a blowing agent that generates a gas under the conditions of the molding process. This can help the substrate polymer to completely fill the mold and reduce overall part weight somewhat. In such cases, the molded substrate will have a reduced bulk density, compared to that of

the unfoamed substrate polymer, and will usually be somewhat cellular. The density of the substrate is preferably at least 10, more preferably at least 25, even more preferably at least about 35 pounds per cubic foot, and in any case is higher than that of any foam that is used as the energy-absorbing component. The optional skin can be any of a wide variety of materials, such as leather, carpeting, synthetic leather, a vinyl sheet or foam-backed vinyl (such as described in US 5,571,355 and 6,213,540, for example). However, the skin material most preferably is a film and/or sheet of the same polymer as the energy-absorbing component (or one classified the same as for recycling purposes), the substrate, or, most preferably, both. A most preferred skin material is a TPO or polypropylene sheet, especially a slush molded TPO or polypropylene sheet.

In the exemplary embodiment shown in Figure 2, composite part 25 comprises energy absorbing component 3, substrate 20 and optional skin 5. The energy absorbing component 3 is affixed directly to substrate 20 along interface 23, without any intervening adhesive layer. Similarly, substrate 20 is affixed directly to skin 5 along interface 26, again without intervening adhesive layer. Skin 5 has an exposed surface 24 that in many embodiments will be the exposed (show) surface of the part. As shown, energy absorbing component 3 has been shaped during the molding process, forming regions 21 and 22 where the energy absorbing component has been densified somewhat in the molding process.

In order to provide the requisite energy-absorption, a thermoplastic energy-absorbing component preferably will have a thickness (greatest distance in the shortest dimension) of at least 5 millimeters, preferably at least about 10 millimeters, even more preferably at least about 13 millimeters, to about 200 millimeters, especially to about 150 millimeters. The thickness of the substrate will depend largely on the form and function of the composite part. Most typically, the function of the substrate will be to provide a rigid layer through which the composite can be attached to the vehicle, and through which other parts can be assembled, and in some cases to provide a smooth backing for a show layer. To meet these functions, a thickness from 0.5 mm, preferably from 1.0 mm, even more preferably from about 1.5 mm to about 50 mm, preferably to about 10 mm, is suitable. Any skin that may be present is typically from about 1 mm to as much as 50 mm in thickness, but skin thickness usually will not exceed about 5 mm.

Many modifications of the composite part are possible. For example, the

part may contain multiple sections of energy-absorbing component, which may be contiguous or separated. Similarly, the substrate may consist of multiple segments that also can be contiguous or separated. An example of this is a sandwich structure, in which substrate sections are molded on either side of the energy-absorbing component. The substrate may wholly or partially encapsulate the energy-absorbing component.

A skin can be provided on either or both sides of the part, and in particular may be applied directly over all or a portion of the energy-absorbing component. To achieve good adhesion, it is usually necessary to employ a heated mold so as to soften the surface of the energy-absorbing component and/or the skin to cause one or both of them to become tacky and adhere to the other. Alternatively, the skin can be pre-heated before being inserted into the mold, until it becomes slightly tacky.

A reinforcing layer can be incorporated into the substrate, for example by laying a reinforcing material into the mold prior to injecting the structural polymer. A suitable method of incorporating a reinforcing mat is described in US 6,171,419, although other methods are suitable as well. The foam may also incorporate a reinforcing material, if desired.

In addition to or instead of a skin, other show surfaces can be incorporated into the part in various ways. Carpet can be vacuum-drawn into the mold and used in place of a skin to form a carpet-covered part. Wood or synthetic wood, leather or synthetic leather or other show surfaces can be applied using the process, by appropriately inserting the materials into the mold prior to molding.

The parts will often contain specialized features to meet performance and/or assembly requirements for their particular applications. Thus, for example, the parts may be formed with bolsters; cut-outs for features such as door handles, audio speakers, controls, air bags and the like; various fasteners for attachment to a vehicle or other vehicular parts; additional features such as arm rests; and the like. These features can be incorporated into the part through appropriate mold design, including these components into the molding process (as described, for example, in US 5,397,409 and 5,171,419, for example) or by post-molding assembly.

Shaped composite parts for automotive applications preferably satisfy one or more of Federal Motor Vehicle Safety (FMVSS) 201U—Occupant Head Impact



Protection, FMVSS 208—Occupant Knee Impact Protection and FMVSS 214—  
Occupant Side Impact Protection standards.

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## CLAIMS:

1. A method of making a shaped part having an integrated energy-absorbing  
5 component, comprising (a) positioning a previously-formed thermoplastic energy-absorbing component into a mold; (b) introducing a molten thermoplastic substrate polymer into the mold, and (c) molding the substrate polymer in the mold under conditions sufficient to form said substrate polymer into a shaped substrate and to  
10 adhere the energy-absorbing component to said substrate while substantially retaining the structure of the energy-absorbing component.
2. The method of claim 1 wherein the energy-absorbing component is an extruded polyolefin foam.
3. The method of claim 1, wherein the substrate polymer is of the same material  
15 as the energy-absorbing component or of a polymer that is classified the same as the energy-absorbing component for recycling purposes.
4. The method of claim 2, wherein the extruded polyolefin foam has a density of less than 20 pounds per cubic foot (320 kg/m<sup>3</sup>).
5. The method of any of claims 2 or 4, wherein the extruded polyolefin foam has a  
density of 0.5 to 10 pounds per cubic foot (80 to 160 kg/m<sup>3</sup>).
- 20 6. The method of any of claims 2 or 4, wherein the extruded polyolefin foam is anisotropic.
7. The method of any of claims 2-6, wherein the extruded polyolefin foam has a compressive strength in at least one direction of no greater than 150 psi (1034 kPa) at 25% strain as measured in accordance with ASTM D3575-93 (Suffix D).
- 25 8. The method of claim 6, wherein the extruded polyolefin foam exhibits a compressive strength in one direction that is at least 1.25 times the compressive strength in one or more other directions.
9. The method of claim 1, wherein the energy-absorbing component is a coalesced strand foam.
- 30 10. The method of any of claims 1-9, further comprising the step of inserting a flexible sheet into the mold in contact with at least one interior surface thereof prior to the introduction of the molten thermoplastic polymer, and introducing the molten substrate polymer such that it comes in contact with the flexible sheet and upon solidifying becomes adhered to the flexible sheet.

11. The method of claim 2, wherein the thickness of the previously-formed thermoplastic foam after the molding step is at least 5 millimeters.
12. The method of claim 11, wherein the thickness of the previously-formed thermoplastic foam after the molding step is from about 5 to about 200  
5 millimeters.
13. The method of claim 2, wherein the previously-formed thermoplastic foam is a TPO or polypropylene, and the substrate polymer is a TPO or polypropylene.
14. The method of claim 13, wherein the flexible sheet is a TPO or polypropylene.
15. The method of claim 1, wherein the energy-absorbing component is an  
10 expanded polystyrene, a styrene/phenylene oxide copolymer or other polystyrene copolymer bead foam.
16. The method of claim 1, wherein the energy-absorbing component is a modular energy-absorbing assembly including a base having a plurality of recesses that each include a floor and walls, wherein the recesses include an opening at the  
15 base, and an overlay is adhered to the base, the floor or both to form a plurality of gas-filled enclosed spaces.
17. A shaped composite having a thermoplastic foam component having a density of less than 10 pounds per cubic foot ( $160 \text{ kg/m}^3$ ) and a thickness of at least 5 millimeters directly adhered, without intervening adhesive, to a thermoplastic  
20 substrate having a density of at least 20 pounds per cubic foot ( $320 \text{ kg/m}^3$ ) and a thickness of at least 1.5 millimeters.
18. The shaped composite of claim 17 wherein the substrate is of the same material as the thermoplastic foam component or a polymer that is classified the same as the thermoplastic foam component for recycling purposes.
- 25 19. The shaped component of claim 17 or 18, which is an energy-absorbing vehicle part.
20. A shaped composite having a thermoplastic modular energy-absorbing assembly including a base having a plurality of recesses that each include a floor and walls, wherein the recesses include an opening at the base, and an overlay is  
30 adhered to the base, covering the opening of each recess to form a plurality of gas-filled enclosed spaces, the energy-absorbing assembly being directly adhered, without intervening adhesive, to a thermoplastic substrate having a density of at least 20 pounds per cubic foot ( $320 \text{ kg/m}^3$ ) and a thickness of at least 1.5 millimeters.

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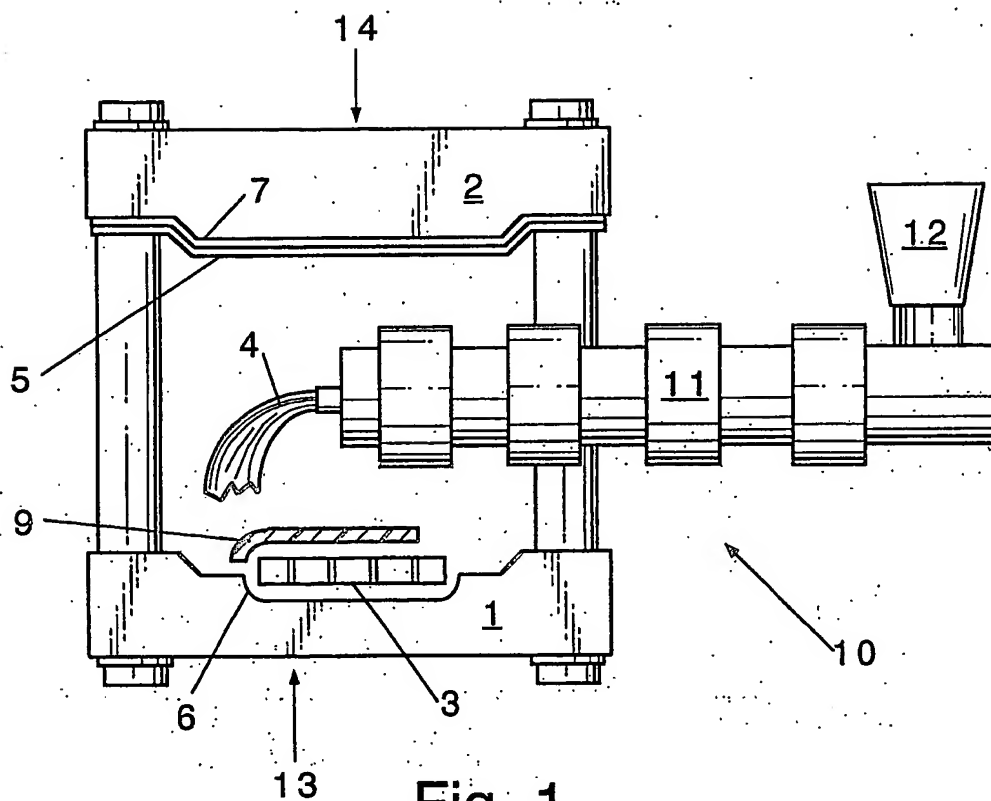


Fig. 1

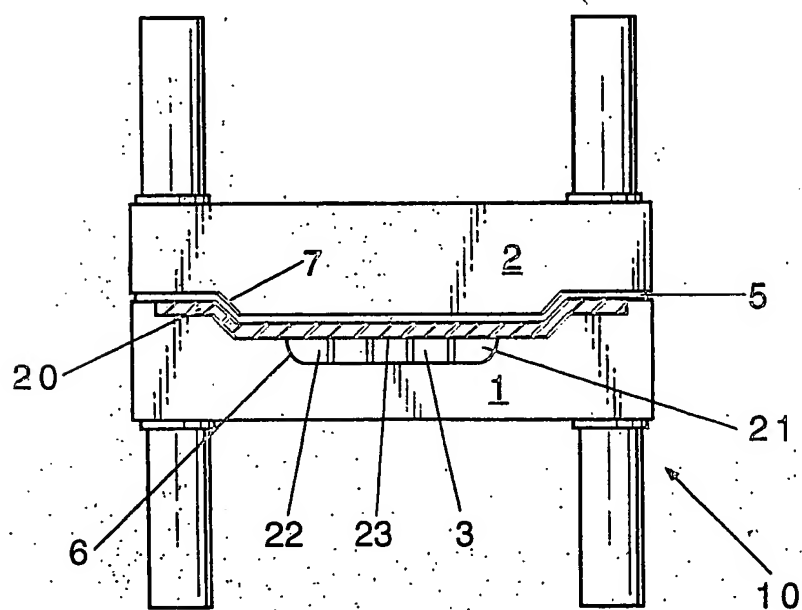


Fig. 1A

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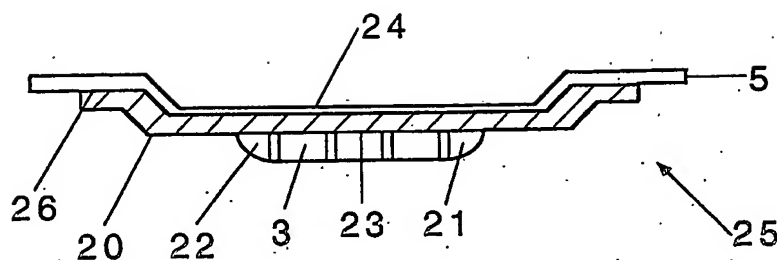


Fig. 2

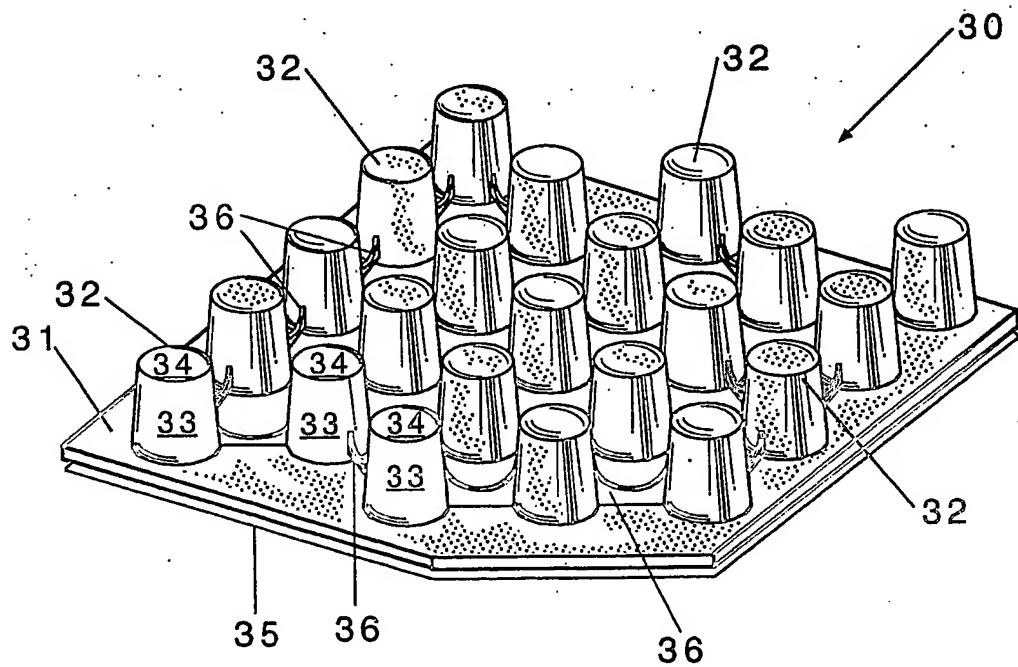


Fig. 3